

SULFUR

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Recovered sulfur production reached an alltime high of 9.4 million metric tons (Mt), with a 6.0% increase from oil refineries, and a slight increase of sulfur production at natural gas processing operations. Even byproduct sulfuric acid production from nonferrous metal smelters, which had been in decline since 2001, increased by 8.2% to reach 739,000 metric tons (t) of contained sulfur. Exports, imports, and consumption increased; producers' stocks decreased.

The United States was once again the world's leading sulfur producer in 2004 with total production of 10.1 Mt of sulfur in all forms. All elemental sulfur and byproduct sulfuric acid was produced as a result of efforts to meet environmental requirements that limit atmospheric emissions of sulfur dioxide. Worldwide, environmental regulations contributed to increased sulfur recovery, and strong worldwide demand slowed the decline in production of native sulfur to about 4.2%, which had been in steep decline since 2000. In the few countries where pyrites remain an important raw material for sulfuric acid production, the sulfur content of pyrites production increased by 5.9%.

Expanded production continued to outpace sulfur demand growth, which resulted in increased stocks at some operations, especially at a few in remote locations from which it is difficult and costly to ship the product to market. Some remelting at more market-accessible stockpiles occurred to meet global demand.

Through its major derivative, sulfuric acid, sulfur ranks as one of the most important elements used as an industrial raw material and is of prime importance to every sector of the world's fertilizer and manufacturing industries. Sulfuric acid production is the major end use for sulfur, and consumption of sulfuric acid has been regarded as one of the best indices of a nation's industrial development. More sulfuric acid is produced in the United States every year than any other inorganic chemical; 37.5 Mt, which is equivalent to about 12.3 Mt of elemental sulfur, was produced in 2004, slightly more than that of 2003 (U.S. Census Bureau, 2005).

In 2004, nearly all salient U.S. sulfur statistics were higher than the corresponding values in 2003. Domestic production and shipments of sulfur in all forms were 5.4% and 5.7% higher, respectively, than those of 2003. Consumption increased, and exports, imports, prices, and values were higher (table 1; figures 1-4). Only stocks were down in 2004.

Estimated world sulfur production was more than 3.5% higher in 2004 than it was in 2003 (table 1). Recovered elemental sulfur is produced primarily during the processing of natural gas and crude petroleum. For the fourth consecutive year, more than 90% of the world's sulfur production came from recovered sources. Some sources of byproduct sulfur are unspecified, which means that the material could be elemental or byproduct sulfuric acid. The quantity of sulfur produced from recovered sources was dependent on the world demand for fuels, nonferrous metals, and petroleum products, rather than for sulfur.

World sulfur consumption was slightly higher than it was in 2003; about 50% was used in fertilizer production, and the remainder, in myriad other industrial uses. World trade of elemental sulfur increased by 9.3% from the levels recorded in 2003. Worldwide inventories of elemental sulfur were relatively unchanged.

Legislation and Government Programs

The U.S. Environmental Protection Agency (EPA) issued the final rule on the sulfur content for nonroad diesel on May 11. This regulation reduced the allowable sulfur level in fuel used in farm and construction equipment to 500 parts per million (ppm) by 2007 and 15 ppm by 2010, from a current limit of 3,000 ppm. The new standards are the same as the requirements for on-road diesel except for the time for implementation. Highway diesel must meet the lower limit by mid-2006. The EPA was working on a similar proposal for diesel burned in marine and locomotive engines (Lorenzetti, 2004).

Production

Elemental Sulfur.—U.S. production statistics were collected on a monthly basis and published in the U.S. Geological Survey (USGS) monthly sulfur Mineral Industry Surveys. All of the 110 operations to which survey requests were sent responded; this represented 100% of the total production listed in table 1. In 2004, production and shipments were about 5.1% and 5.6% higher than those of 2003. The value of shipments was 19.5% higher than in 2003 owing to an increased average unit value of elemental sulfur. Trends in sulfur production are shown in figures 1 and 3.

Frasch.—Until 2000, native sulfur associated with the caprock of salt domes and in sedimentary deposits in the United States was mined by the Frasch hot-water method in which the native sulfur was melted underground with super-heated water and brought to the surface by compressed air. Freeport-McMoRan Sulphur Inc. (a subsidiary of McMoRan Exploration Co.) closed the last domestic Frasch mine, Main Pass, in 2000 (Fertilizer Markets, 2000).

Recovered.—Recovered elemental sulfur, which is a nondiscretionary byproduct from petroleum-refining, natural-gas-processing, and coking plants, was produced primarily to comply with environmental regulations that were applicable directly to emissions from the processing facility or indirectly by restricting the sulfur content of the fuels sold or used by the facility. Capacity utilization at U.S. refineries was about 96% during the year (North American Sulphur Review, 2004d). Recovered sulfur was produced by 38

companies at 109 plants in 26 States and 1 plant in the U.S. Virgin Islands. Most of these plants were small with only 36 reporting production that exceeded 100,000 metric tons per year (t/yr). By source, 78.8% of recovered elemental sulfur production came from petroleum refineries or satellite plants that treated refinery gases and coking plants, and the remainder was produced at natural-gas treatment plants (table 3).

The leading producers of recovered sulfur, all with more than 500,000 t of sulfur production, in descending order of production, were Exxon Mobil Corp., BP p.l.c., ConocoPhillips Co., Chevron Corp., Valero Energy Corp., Shell Oil Co. (including its joint-ventures with Petróleos Mexicanos, S.A. de C.V. and Saudi Refining Inc. and subsidiary operations), CITGO Petroleum Corp. (including its joint-venture refinery it owns with Lyondell Chemical Co.), and Burlington Resources Inc. The 65 plants owned by these companies accounted for 78.6% of recovered sulfur output during the year. Recovered sulfur production by State and district is listed in tables 2 and 3.

Four of the world's 17 largest refineries, each with a crude processing capacity of nearly 450,000 billion barrels per day or more, are in the United States. They are, in decreasing order of production, ExxonMobil's Baytown, TX, refinery; Hovensa LLC's St. Croix, VI, refinery; ExxonMobil's Baton Rouge, LA, refinery; and BP's Texas City, TX, refinery (Nakamura, 2004). The capacity to process large quantities of crude oil does not necessarily mean that refineries recover large quantities of sulfur, but all of these refineries were major producers of refinery sulfur. Sulfur production depends on installed sulfur recovery capacity as well as the types of crude oil that are refined at the specific refineries. Major refineries that process low-sulfur crudes may have relatively low sulfur production.

U.S. refineries were installing equipment to meet the lower sulfur limits on finished fuels that took effect in 2004 and others that will take effect in 2006. Expensive processes were necessary to meet these requirements, but several refiners were also installing additional equipment to enable refineries to process heavy, sour crudes, especially those from Canada, Mexico, and Venezuela (North American Sulfur Review, 2004h).

Byproduct Sulfuric Acid.—Sulfuric acid production at copper, lead, molybdenum, and zinc roasters and smelters accounted for about 7.3% of the total domestic production of sulfur in all forms and totaled 739,000 t; this was an increase of 8.2% compared with that of 2003 (table 4). Three acid plants operated in conjunction with copper smelters, and three were accessories to lead, molybdenum, and zinc smelting and roasting operations. The three largest sulfuric acid plants were associated with copper mines and accounted for 81.2% of the output. The copper producers—ASARCO Incorporated, Kennecott Utah Copper Corp., and Phelps Dodge Corp.—each operated a sulfuric acid plant at their primary copper smelters.

Consumption

Apparent domestic consumption of sulfur in all forms was 7.7% higher than that of 2003 (table 5). Of the sulfur consumed, 71.5% was obtained from domestic sources—elemental sulfur (66.3%) and byproduct acid (5.3%)—compared with 73.5% in 2003 and 74.6% in 2002. The remaining 28.5% was supplied by imports of recovered elemental sulfur (22.3%) and sulfuric acid (6.1%). The USGS collected end-use data on sulfur and sulfuric acid according to the standard industrial classification of industrial activities (table 6).

Sulfur differs from most other major mineral commodities in that its primary use is as a chemical reagent rather than as a component of a finished product. This use generally requires that it be converted to an intermediate chemical product prior to its initial use by industry. The leading sulfur end use, sulfuric acid, represented 59.1% of reported consumption with an identified end use, and it is reasonable to assume that nearly all of the sulfur consumption reportedly used in petroleum refining was first converted to sulfuric acid, bringing sulfur used in sulfuric acid to 86.8% of the total. Some identified sulfur end uses were tabulated in the "Unidentified" category because these data were proprietary. Data collected from companies that did not identify shipment by end use also were tabulated as "Unidentified." A significant portion of the sulfur in the "Unidentified" category may have been shipped to sulfuric acid producers or exported, although data to support such assumptions were not available.

Because of its desirable properties, sulfuric acid retained its position as the most universally used mineral acid and the most produced and consumed inorganic chemical, by volume. Data based on USGS surveys of sulfur and sulfuric acid producers showed that reported U.S. consumption of sulfur in sulfuric acid (100% basis) decreased slightly. Reported consumption figures do not correlate with calculated apparent consumption owing to reporting errors and possible double counting in some data categories. These data are considered independently from apparent consumption as an indication of market shares rather than actual consumption totals.

Agriculture was the leading sulfur-consuming industry; consumption increased to 9.11 Mt compared with 8.51 Mt in 2003. Reported consumption of sulfur in the production of phosphatic fertilizers was 3.2% more than that of 2003, and reported consumption of sulfur used in other agricultural chemicals including sulfur fertilizers increased by 23.3%. According to export data from the U.S. Census Bureau (2005), the estimated quantity of sulfur needed to manufacture exported phosphatic fertilizers decreased slightly to 5.1 Mt.

The second ranked end use for sulfur was in petroleum refining and other petroleum and coal products. Producers of sulfur and sulfuric acid reported a 13.2% increase in the consumption of sulfur in that end use. Demand for sulfuric acid in copper ore leaching, which was the third ranked end use, increased by 7.4% as a result of increased copper production from leaching operations.

The U.S. Census Bureau (2005) also reported that 3.08 Mt of sulfuric acid was produced as a result of recycling spent and contaminated acid from petroleum alkylation and other processes. Two types of companies recycle this material—companies that produce acid for consumption in their own operations and also recycle their own spent acid and companies that provide acid regeneration services to sulfuric acid users. The petroleum refining industry was believed to be the leading source and consumer of recycled acid for use in its alkylation process.

Stocks

Yearend inventories held by recovered elemental sulfur producers decreased to 185,000 t, or about 10% less than that of 2003 (table 1). Based on apparent consumption of all forms of sulfur, combined yearend stocks amounted to about a 5-day supply in 2004, compared with a 6-day supply in 2003, a 6-day supply in 2002, an 8-day supply in 2001, and a 6-day supply in 2000. Final stocks in 2004 represented 3.3% of the quantity held in inventories at the end of 1976 when sulfur stocks peaked at 5.65 Mt; this was a 7.4-month supply at that time (Shelton, 1978, p. 1296).

Although markets were favorable throughout the year, U.S. producers and logistics companies on the Gulf of Mexico were planning for the possibility of excess supplies in the future. Most refineries face difficult choices when sulfur production exceeds demand and could be forced to curtail refining if no outlet for sulfur is available. In addition, increased international demand for sulfur has created new markets for exported sulfur. For this reason, several sulfur forming projects were progressing. CF Martin Sulphur, L.P., a sulfur logistics company, was considering the construction of a sulfur forming facility in Beaumont, TX (North America Sulphur Review, 2004f). Gulf Sulphur Services Ltd. (a joint venture between The Mosaic Co. and Savage Industries, Inc.) announced plans to build a sulfur priller and sulfur terminal at Mosaic's Faustina, LA, phosphate plant. The facility will have sulfur forming, handling, and storage capabilities (North American Sulphur Review, 2004a). Oil refiners on the Gulf of Mexico were considering the installation of sulfur forming equipment at or near a port to protect against oversupply problems that would limit operations at their refineries. Plans were to build tanks to store about 24,000 t of molten sulfur and the capacity to form approximately 4,000 metric tons per day (t/d) (North American Sulphur Review, 2004c). When completed, all these facilities were expected to be used when surplus sulfur supplies make it necessary to seek alternative markets. In that way, these producers would have the alternative to seek international customers when sulfur was in oversupply in the Gulf of Mexico region.

Prices

The contract prices for elemental sulfur at terminals in Tampa, FL, which are reported weekly in Green Markets, began the year at \$67.50 to \$70.50 per metric ton. In August, prices decreased to \$63.50 to \$66.50 per ton and remained there until November when they fell to \$61.50 to \$64.50 per ton and remained at that level through the remainder of the year.

Based on total shipments and value reported to the USGS, the average value of shipments for all elemental sulfur was estimated to be \$32.50 per ton, which was 13.2% higher than that of 2003 and nearly three times the average value in 2002. This dramatic increase was a result of a strong U.S. economy, increased production at domestic phosphate fertilizer operations that consumes large quantities of sulfur, and increased sulfur demand worldwide. Prices vary greatly on a regional basis, which caused the price discrepancies between Green Markets and USGS data. Tampa prices were usually the highest reported because of the large sulfur demand in the central Florida area. At the beginning of 2004, U.S. west coast prices were listed at \$15 to \$20 per ton, higher values than these producers have obtained for many years. Nearly all the sulfur produced in this region is processed at forming plants, incurring substantial costs to make solid sulfur in acceptable forms that can be shipped overseas. The majority of west coast sulfur was shipped overseas. From May through December, west coast prices remained between \$12 and \$17 per ton.

Foreign Trade

Exports of elemental sulfur from the United States, which included the U.S. Virgin Islands, as listed in table 7, were 13.0% higher in quantity than those of 2003 and 16.4% higher in value because the average unit value of U.S. export material increased to \$66.68 per ton. Exports from the west coast were 668,000 t, or 70.4% of total U.S. exports.

The United States continued to be a net importer of sulfur. Imports of elemental sulfur exceeded exports by almost 2 Mt. Recovered elemental sulfur from Canada and Mexico delivered to U.S. terminals and consumers in the liquid phase furnished about 89.6% of all U.S. sulfur import requirements. Total elemental sulfur imports were slightly lower in quantity, but higher prices resulted in the value being 8.8% higher than it was in 2003. Imports from Canada, mostly by rail, were 3.4% lower in quantity, and waterborne shipments from Mexico were slightly higher than those of 2003 (table 9). Imports from Venezuela were estimated to account for about 10.4% of all imported elemental sulfur.

In addition to elemental sulfur, the United States also had significant trade in sulfuric acid. Sulfuric acid exports were slightly lower than those of 2003 (table 8). Sulfuric acid imports were 11.8 times that of exports (tables 8, 10). Canada and Mexico were the sources of 89.0% of U.S. sulfuric acid imports, most of which were probably byproduct acid from smelters. Canadian and some Mexican shipments to the United States came by rail, and the remainder of imports came primarily by ship from Europe. The tonnage of sulfuric acid imports was 2.64 times that of 2003, and the value of imported sulfuric acid increased in proportion. Although still a minor portion of sulfur imports, additional imported sulfuric acid was required to meet the increased demand for sulfur in all forms. The most dramatic increase was in imports from Canada.

World Industry Structure

The global sulfur industry remained divided into two sectors—discretionary and nondiscretionary. In the discretionary sector, the mining of sulfur or pyrites is the sole objective; this voluntary production of native sulfur or pyrites is based on the orderly mining of discrete deposits with the objective of obtaining as nearly a complete recovery of the resource as economic conditions permit. In the nondiscretionary sector, sulfur or sulfuric acid is recovered as an involuntary byproduct—the quantity of output subject to demand for

the primary product irrespective of sulfur demand. Discretionary sources, once the primary sources of sulfur in all forms, represented 9.4% of the sulfur produced in all forms worldwide as listed in table 11.

Poland was the only country that produced more than 500,000 t of native sulfur by using either the Frasch or conventional mining methods (table 11). Small quantities of native sulfur were produced in Asia, Europe, and South America. The importance of pyrites to the world sulfur supply has significantly decreased; China and Finland were the only countries of the top producers with more than 500,000 t of sulfur produced whose primary sulfur source was from pyrites. About 78.3% of world pyrites production was in China, and 7.1% in Finland.

Of the 22 countries listed in table 11 that produced more than 500,000 t of sulfur, 15 obtained the majority of their production as recovered elemental sulfur. These 22 countries produced 90.2% of the total sulfur produced worldwide. The international sulfur trade was dominated, in descending order of quantity, by Canada, Russia, Saudi Arabia, the United Arab Emirates, Japan, and Iran; these countries exported more than 1 Mt of elemental sulfur each and accounted for 72.2% of total sulfur trade. Major sulfur importers, in descending order, were China, Morocco, the United States, India, Brazil, and Tunisia, all with imports of more than 1 Mt.

World production of sulfur was 3.5% higher in 2004 than it was in 2003; consumption was believed to be comparably higher also, making 2004 the 13th consecutive year that sulfur production exceeded consumption.

Prices in most of the world were believed to have averaged higher throughout the year than in the previous year, for the third consecutive year. Production of Frasch sulfur was slightly lower than that of 2003; production at the last mine in Poland remained about the same. Recovered elemental sulfur production was 3.8% higher, and byproduct sulfuric acid production increased slightly compared with those of 2003. Supplies of sulfur in all forms continued to exceed demand; worldwide sulfur inventories increased, much of which was stockpiled in Canada and Kazakhstan, although Canadian stocks actually declined owing to the strong international demand for sulfur. Globally, production of sulfur from pyrites was 5.9% higher.

Statistics compiled by the Oil & Gas Journal showed that the United States possessed 20.4% of the world's total refining capacity and 42.5% of the world's sulfur recovery capacity derived from oil refineries. The publication listed 674 oil refineries in 115 countries; only about one-half of these countries were reported to have sulfur recovery capacity (Stell, 2004[§]). Although the sulfur recovery data appeared to be incomplete, analysis of the data showed that most of the countries that reported no sulfur recovery at refineries were small and had developing economies and limited refining industries. In general, as refining economies improve in developing countries and the refining industries mature, additional efforts are made to reduce atmospheric emissions through installation of sulfur recovery units.

One of the few unregulated sources of manmade pollution is marine shipping. Marine pollution has thus far been left to shippers under the International Marine Organization's (IMO) Marine Pollution Treaty (MARPOL). An amendment to MARPOL that was ratified in October limited sulfur to 4.5% for ships in general operation beginning May 19, 2005. The allowable sulfur content of fuel burned in ships operating in the most crowded European waters [the North Sea, the English Channel, and the Baltic Sea, collectively known as the SO_x emission control area (SECA)] was reduced to 1.5% effective May 19, 2006 (Fertilizer Week, 2004b).

The European environmental ministers' final proposal for the sulfur content in fuels for vessels sailing in European waters was a limit of 1.5% sulfur for all vessels in the SECA starting in 2007. The 1.5% limit applies to passenger vessels between ports within the European Union (EU) and the Baltic Sea beginning in May 2006 and the North Sea and the English Channel by 2007. Ships at berth in EU ports will be required to burn 0.1% sulfur fuel starting in January 2010 (Sulphur, 2004c).

Sulfur production in the Middle East is expected to increase to 7.5 Mt in 2012 from about 5.4 Mt in 2004. The expanded sulfur production can be attributed in large part to increased environmental awareness in the region, where it has become less acceptable to flare hydrogen sulfide instead of recovering sulfur. Most increased production will come from Iran, Qatar, Saudi Arabia, and the United Arab Emirates (Sulphur, 2004g).

World Review

Canada.—Canada was second only to the United States in production of byproduct sulfur and sulfur in all forms. It led the world in exports of elemental sulfur and stockpiled material. The majority of sulfur production came from natural gas plants in Alberta. For the second consecutive year, strong demand prompted remelting of stocks in Canada, resulting in a decrease of 1 Mt. At yearend, Canadian stocks were estimated to be about 13 Mt (North American Sulphur Review, 2005). Canadian offshore exports were 6.2 Mt, an increase of 17% compared with 2003, much of it going to China. Only one oil sands operation needed to stockpile sulfur, the bulk of Canadian production finding markets. Sulfur recovery at natural gas operations increased slightly, the first increase since 1998. Oil sands operations saw significant increases in sulfur recovery, with a combined 50% increase from three operations (North American Sulphur Review, 2004g).

Canadian production from natural gas has been declining for the past several years. A deposit discovered in 2004 could partially reverse that trend when it is tied in to existing processing plants in 2005. The estimated resource was reported to be 500 billion to 800 billion cubic feet of gas containing 35% hydrogen sulfide, the sulfur from which will be recovered at a rate of about 1,000 t/d (North American Sulphur Review, 2004b).

Alberta has huge deposits of oil sands with estimated reserves of 300 billion barrels of recoverable crude oil that contain 4% to 5% sulfur (Stevens, 1998). The crude oil resource in oil sands in Alberta is larger than the proven reserves of crude oil in Saudi Arabia. As traditional petroleum production in Canada declined, oil sands became a more important source of petroleum for the North American market. The proportion of Canadian production from oil sands was expected to increase to 21% in 2005 and 30% in 2010 from 9% in 2001 (Pok, 2002). Oil sands mines were being expanded by several companies. Because the bitumen recovered at the oil

¹ A reference that includes a section mark (§) is found in the Internet Reference Cited section.

sands deposits is high-density, high-sulfur petroleum, it must be upgraded to higher quality products or refineries must be adapted to process this type of raw material. Canadian upgraders and oil refineries were undergoing expansions and conversions to enable the processing of additional bitumen from expanded oil sands production. U.S. oil refiners were upgrading refineries in Colorado, Kentucky, Michigan, Minnesota, and Ohio to process synthetic crudes from Canada.

China.—China was the world's leading producer of pyrites with 56.3% of its sulfur in all forms coming from that source. The country also led in sulfur imports in 2004 with nearly 6.9 Mt (International Fertilizer Industry Association, 2005).

China's expanding industrialization has resulted in increased production of sulfuric acid, growing at an average rate of 8.2% per year from 1994 to 2003. In 2004, 38.7% of Chinese sulfuric acid production was from pyrites, 37.4% from elemental sulfur, 22.3% from smelter gases, and 1.6% from phosphogypsum. As in the United States, the major use for sulfuric acid was in the production of phosphate fertilizer. Sulfuric acid production was expected to reach 36 Mt in 2004, 38 Mt in 2005, and 42 Mt in 2010. Elemental sulfur and smelter gases are expected to become the more important raw materials for sulfuric acid production, and pyrites should become less dominant. Production of elemental sulfur is expected to increase as more is recovered at petroleum refineries (Sulphur, 2004g).

China's State Environmental Protection Administration (SEPA) drafted new vehicle emission standards equivalent to those enacted in Europe that were expected to be in force by 2008. Chinese motor fuels contain up to eight times more sulfur than gasoline in Europe and the United States. Vehicle emissions were the leading source of air pollution in China, having overtaken emissions from industry. The SEPA estimated that car exhaust would account for 79% of urban air pollution in 2005 (Sulphur, 2004a).

Because China has had serious air quality problems, especially in cities, the Government of China imposed a sulfur limit of 0.2% in diesel since 2000 to try to improve conditions. Beginning in 2001, 0.05% sulfur diesel was available in Beijing, Guangzhou, and Shanghai. Hong Kong requires even lower sulfur content in diesel used there. Additional sulfur recovery capacity will be required for China to expand the clean-fuel requirements to the entire country. Refiners must import more expensive, low-sulfur crude petroleum because the country lacks sulfur recovery capabilities (Vautrain, 2004).

Iraq.—One of the world's largest sulfur deposits is in northern Iraq where capacity was in place to produce 1 Mt per year of Frasch sulfur. Following Iraq's invasion of Kuwait in 1990, details on production at that mine were difficult to determine. It is believed that production continued at reduced levels until 2003, and stockpiles had accumulated. Scientists from the University of Maryland calculated that a fire at the Mishraq Mine sulfur stockpile, which was caused by sabotage in 2003, was the largest manmade release of sulfur dioxide ever recorded. The fire burned for almost 1 month and produced more sulfur dioxide than most volcanic eruptions. The fire released an estimated 600,000 t of sulfur dioxide, causing significant respiratory problems for the local population and \$40 million worth of damage to crops, although they expect no long-term environmental effects. Data was collected using instruments on two of the National Aeronautical and Space Administration's satellites (Sulphur, 2004e).

Kazakhstan.—The Tengiz oilfield and gasfield is the main source of current sulfur production in Kazakhstan. Located on the northeastern shore of the Caspian Sea in western Kazakhstan, Tengiz has been operated by Tengizchevroil (TCO) since 1993. The owners of TCO are ChevronTexaco (50%), ExxonMobil (25%), KazakhOil National Oil and Gas Co. (Kazakhstan's national oil and gas company) (20%), and LUKARCO (a joint venture between BP and Russian oil company LUKoil Oil Co.) (5%) (Chevron Corp., 2000). One of the world's large oilfields, Tengiz contains high-quality oil with 0.49% sulfur and associated natural gas that contains 12.5% hydrogen sulfide (Connell and others, 2000).

Production capacity at Tengiz was about 1.2 Mt in 2004, and it was expected to increase to 2.4 Mt in 2006. Stockpiled material, which was a source of contention between TCO and the Government of Kazakhstan in 2003, was estimated to be 8.5 Mt in 2004. Forming capacity that was installed to facilitate exports and minimize additional stockpiles totaled 800,000 t/yr for granulation and 400,000 t/yr for flaking. Granulation capacity was expected to increase to 1.6 Mt in 2006 (van Meurs, 2004, p. 3).

Sulfur also is recovered from the Karachaganak gas-condensate field in Kazakhstan near the Russian border. Because it is close to the Russian gas processing operation in Orenberg, sour gas from Karachaganak is treated at Orenberg. No gas treatment facilities have been installed at Karachaganak (Sulfur, 2001a).

Another large oilfield and gasfield was being developed in Kazakhstan by ExxonMobil (16.67%), Agip (16.67%), British Gas (16.67%), Shell (16.67%), ConocoPhillips (8.33%), and Inpex Corp. (8.33%). The consortium of companies agreed to the operating conditions for the giant Kashagan oilfield and gasfield under development in the Caspian Sea off Kazakhstan. Initial production was expected in 2008, and had the potential to make Kashagan one of the single largest resources of sulfur in the world. Actual production hinged on how much sulfur was reinjected (Sulphur, 2004d). Environmental groups objected to the implementation of acid gas reinjection at the field before extensive testing was completed that showed the technology presented no risk of contaminating the region with hydrogen sulfide and other sulfur compounds (Sulphur, 2004b).

Qatar.—Recovered sulfur production from natural gas processing in Qatar was estimated to be 360,000 t in 2004. Expansions of gas production in North Field are expected to result in dramatic increases of sulfur production starting in 2006 when sulfur production is expected to reach 735,000 t. Production potential increases were estimated to be 1.85 Mt in 2010 and 4.2 Mt in 2014. No stockpiling will be allowed. Because Qatar has only one deepwater port in the Arab Gulf and limited domestic demand for sulfur, reinjection of acid gases is being considered (van Meurs, 2004).

Russia.—Russia ranked second in the world in sulfur exporting with more than 4.3 Mt of elemental sulfur exports in 2004 (International Fertilizer Industry Association, 2005). The majority for Russia's sulfur production comes from natural gas at Gazprom's gas processing plants in Astrakhan and Orenburg, with an estimated 5 Mt of production in 2004.

Norilsk Nickel in Russia planned emission control improvements that would result in the recovery of 800,000 t/yr of sulfur from its smelters. The company planned to reduce sulfur dioxide emissions by 70% at its nickel smelter in north central Siberia by 2010 and recover elemental sulfur rather than the more common sulfuric acid from smelters. Pechanganickel aimed to reduce emissions at its nickel smelter near Murmansk by 90% (Sulphur, 2004f).

Venezuela.—Venezuela's Orinoco Basin is one of the world's major resources of crude oil. The crude petroleum found there is low-quality oil with sulfur content averaging about 4%, similar to the bitumen from Canadian oil sands operations. To make the material attractive for the open market, it had to be upgraded to higher quality synthetic crude with lower sulfur content before being shipped to foreign markets for further refining. Four operations processed Orinoco crudes at the Jose complex. They are Petrozuata [a joint venture between Conoco Inc. and Petr leos de Venezuela S.A. (PdVSA)], Sincor [an alliance of Total (47%), PdVSA (38%), and Statoil AS (15%)], the Cerro Negro project (a venture of ExxonMobil, PdVSA, and Veba Oel AG of Germany), and the Hamaca joint venture (owned by PdVSA, Chevron, and ConocoPhillips).

Completion of the Hamaca crude oil upgrading facility raised that operation's sulfur production capacity to 200,000 t/yr, bringing total capacity at the Jose industrial complex to 500,000 t/yr. Facilities there upgrade heavy crude petroleum to high-quality synthetic crude and, in the process, recover elemental sulfur, much of which is exported to the United States (Fertilizer Week, 2004a).

The Government of Venezuela increased the royalty on extra-heavy-oil-upgrading projects in Venezuela to 16.6% from 1%. Although the new rate is closer to a rate typical in the industry, the unexpected increase raised questions about future developments in that country and its commitment to honor agreements to encourage outside investments in domestic projects (North American Sulphur Review, 2004e).

Outlook

The sulfur industry continued on a path of increased production, slow growth in consumption, higher stocks, and expanded world trade. U.S. production from petroleum refineries is expected to increase substantially in the next few years as expansions, upgrades, and new facilities at existing refineries are completed, thus enabling refiners to increase throughput of crude oil and to process higher sulfur crudes. Production from natural gas operations was higher than it was in 2003, but significant decreases are expected from gas operations in Wyoming, the State in which about 70% of all U.S. natural gas sulfur is recovered. Of four large gas operations in the State, three expected decreases in production in 2004. Production at two decreased as a natural function of long-term extraction of natural gas. The operator of another gas plant was installing sour gas reinjection apparatus that would eliminate production at that site. The final company recently expanded its operation but was exploring the possibility of storing excess production underground. Theoretically, this material would be available to meet future needs. In reality, however, it represented an option for disposing of unwanted surplus material.

Worldwide recovered sulfur output is expected to continue to increase. The largest increases in recovered sulfur production through 2005 are expected to come from the Middle East's and Russia's growth in sulfur recovery from natural gas, Canada's expanded oil sands operations, and Asia's improved sulfur recovery at oil refineries. Refineries in developing countries should begin to improve environmental protection measures and in the future eventually approach the environmental standards of plants in Japan, North America, and Western Europe.

Experts from the natural gas industry estimated that the world demand for natural gas will grow by 2.5% per year during the next 20 years for a total 50% increase in demand. Producing 50% more gas means recovering at least an additional 50% in sulfur from that source. Future gas production, however, is likely to come from deeper, hotter, and more sour deposits that will result in even more excess sulfur production unless more efforts are made to develop new large-scale uses for sulfur. Other alternative technologies for reinjection and long-term storage to eliminate some of the excess sulfur supply will require further investigation to handle the quantity of surplus material anticipated (Hyne, 2000).

Byproduct sulfuric acid production will remain relatively steady in the United States so long as the copper smelters remain idle. With the copper industry's switch to lower cost production processes and producing regions, the four idle smelters may never reopen.

Worldwide, the outlook is different. Because copper production costs in some countries are lower than in the United States, acid production from those countries has not decreased as drastically, and increased production is likely. Environmental controls have been less of a concern in developing countries in the past. Many copper producers in developing and even in developed countries, however, are installing more efficient sulfuric acid plants to limit sulfur dioxide emissions at new and existing smelters. Planned and in-progress improvement projects could increase byproduct acid production significantly, although growth has been slower than previously expected.

Frasch sulfur and pyrites production, however, have little chance of significant long-term increases, although higher sulfur prices have resulted in the temporary increases in pyrites production and consumption. Because of the continued growth of elemental sulfur recovery for environmental reasons rather than demand, discretionary sulfur has become increasingly less important as demonstrated by the decline of the Frasch sulfur industry. The Frasch process has become the high-cost process for sulfur production. Pyrites, with significant direct production costs, is an even higher cost raw material for sulfuric acid production when the environmental aspects are considered. Discretionary sulfur output should show a steady decline. The decreases will be pronounced when large operations are closed outright for economic reasons, as was the case in 2000 and 2001. Sulfur and sulfuric acid will continue to be important in agricultural and industrial applications, although consumption will be less than production. World sulfur demand for fertilizer is forecast to increase by about 2.3% per year for the next 10 years; industrial demand is predicted to grow by 2.2% per year as a result of increased demand for copper and nickel leaching.

The most important changes in sulfur consumption will be in location. Phosphate fertilizer production, where most sulfur is consumed, is projected to increase by about 2.0% per year through 2011. With new and expanding phosphate fertilizer capacity in Australia, China, and India, sulfur demand will grow in these areas at the expense of some phosphate operations elsewhere, thus transferring sulfur demand rather than creating new demand. The effects were already being felt by the U.S. phosphate industry as reflected in the permanent closure of some facilities and reduced production at others. U.S. phosphate products supply domestic requirements, but a large portion of U.S. production is exported. Brazil, China, and India are primary markets for U.S. phosphatic

fertilizers. As the phosphate fertilizer industries develop in these countries, some of the markets for U.S. material could be lost. Sulfur will be required for phosphate production at new operations, and more sulfur producers will be competing for those markets.

Use of sulfur directly or in compounds as fertilizer is expected to increase, but this use will be dependent on agricultural economies and increased acceptance of the need for sulfur in plant nutrition. If widespread use of plant nutrient sulfur is adopted, then sulfur consumption in that application could be significant; thus far, however, growth has been slow.

Industrial sulfur consumption has more prospects for growth than in recent years, but still not enough to consume all projected surplus production. Conversion to or increases in copper leaching by producers that require significantly more sulfuric acid for the leaching operations than was used in 2003 bode well for the sulfur industry. Nickel pressure acid leach operations were using increased quantities of sulfur. Changes in the preferred methods for producing oxygenated gasoline, especially in Canada and the United States, might result in additional alkylation capacity that would require additional sulfuric acid. Other industrial uses show less potential for expansion. Production is expected to surpass demand well into the future.

Unless less traditional uses for elemental sulfur increase significantly, the oversupply situation will result in tremendous stockpiles accumulating around the world. In the 1970s and 1980s, research was conducted that showed the effectiveness of sulfur in several construction uses that held the promise of consuming huge quantities of sulfur in sulfur-extended asphalt and sulfur concretes. In many instances, these materials were found to be superior to the more conventional products, but their use so far has been very limited. Interest in these materials seemed to be increasing but only in additional research. When sulfur prices are high as they were in 2004, they are less attractive for unconventional applications where low-cost raw materials are the goal.

Regardless of the prevailing price increases in 2004 that signaled tight supplies, the worldwide oversupply situation is likely to continue. Unless measures are taken to use more sulfur, either voluntarily or through government mandate, large quantities of excess sulfur could be amassed in many more areas of the world, including the United States.

References Cited

- Chevron Corp., 2000, Chevron finalizes additional stake in Tengiz joint venture: San Francisco, CA, Chevron Corp. press release, August 29, 1 p.
- Connell, Dave, Ormiston, Bob, Amott, Nick, and Cullum, Irene, 2000, Gas-plant update moves Tengiz field toward 2004 producing target: *Oil & Gas Journal*, no. 98.24, June 12, p. 64-72.
- Fertilizer Markets, 2000, Main Pass closed: *Fertilizer Markets*, v. 11, no. 4, September 4, p. 9.
- Fertilizer Week, 2004a, PDVSA to raise sulphur output at San Jose: *Fertilizer Week*, v. 18, no. 19, September 3, p. 3.
- Fertilizer Week, 2004b, Shipping industry set for cleaner fuel: *Fertilizer Week*, v. 18, no. 26, October 22, p. 5.
- Hyne, J.B., 2000, An invisible hill to climb: *Sulphur*, no. 269, July-August, p. 3.
- International Fertilizer Industry Association, 2005, Preliminary sulphur and sulphuric acid statistics—2003-2004: Paris, France, International Fertilizer Industry Association A/05/75, 6 p.
- Lorenzetti, Maureen, 2004, Watching government—Generational fuel: *Oil & Gas Journal*, no. 102.19, May 17, p. 29.
- Nakamura, David, 2004, Worldwide refining capacity creeps ahead in 2004: *Oil & Gas Journal*, no. 102.47, December 20, p. 46-53.
- North American Sulphur Review, 2004a, First sulphur forming facility in US Gulf is committed, signaling potential surplus: *North American Sulphur Review*, v. 15, no. 10, October, p. 1.
- North America Sulphur Review, 2004b, Major new sour gas find by Shell Canada in central Alberta to be tied in during 2005: *North America Sulphur Review*, v. 15, no. 12, December, p. 1.
- North American Sulphur Review, 2004c, News and developments: *North American Sulphur Review*, v. 15, no. 2, February, p. 1.
- North American Sulphur Review, 2004d, News and developments: *North American Sulphur Review*, v. 15, no. 7, July, p. 2.
- North American Sulphur Review, 2004e, News and developments: *North American Sulphur Review*, v. 15, no. 10, October, p. 1-2.
- North America Sulphur Review, 2004f, News and developments: *North America Sulphur Review*, v. 15, no. 11, November, p. 1.
- North America Sulphur review, 2004g, Review and outlook/Canada: *North America Sulphur Review*, v. 15, no. 12, December, p. 8.
- North American Sulphur Review, 2004h, US refiners continue to invest in sour crude processing capability: *North American Sulphur Review*, v. 15, no. 3, March, p. 1-2.
- North America Sulphur Review, 2005, Supply/Canada: *North America Sulphur Review*, v. 16, no. 4, April, p. 4.
- Pok, Joe, 2002, Oil sands developments in Alberta and the implications on sulfur supply: International Fertilizer Industry Association Production and International Trade Conference, Quebec City, Quebec, Canada, October 16-18, 2002, Presentation, 15 p.
- Shelton, J.E., 1978, Sulfur and pyrites in Metals and Minerals: U.S. Bureau of Mines Minerals Yearbook 1976, v. I, p. 1287-1307.
- Stevens, Jason, 1998, Oil sands projects gather pace: *Sulphur*, no. 254, January-February, p. 27-30.
- Sulphur, 2001, Rising profile: *Sulphur*, no. 273, March-April, p. 17-19.
- Sulphur, 2004a, China to meet Euro III fuel standard: *Sulphur*, no. 294, September-October, p. 14.
- Sulphur, 2004b, Eco-groups fear effects of gas injection: *Sulphur*, no. 294, September-October, p. 14.
- Sulphur, 2004c, EU ministers set schedule for marine S rules: *Sulphur*, no. 294, September-October, p. 13-14.
- Sulphur, 2004d, Kashagan partners agree operating plan: *Sulphur*, no. 292, May-June, p. 12-13.
- Sulphur, 2004e, Mishraq fire was worst ever for SO₂ emissions, say scientists: *Sulphur*, no. 295, November-December, p. 10.
- Sulphur, 2004f, Norilsk sets standards for SO₂ clean-up: *Sulphur*, no. 291, March-April, p. 10-11.
- Sulphur, 2004g, A region with potential: *Sulphur*, no. 293, July-August, p. 15-22.
- U.S. Census Bureau, 2005, Inorganic fertilizer materials and related products—First quarter 2005: U.S. Census Bureau MQ325B(05)-1, June, 6 p.
- van Meurs, D., 2004, Sulphur developments in Kazakhstan, in British Sulphur Events Sulphur 2004 Conference, Barcelona, Spain, October 24-27, 2004, Proceedings: London, United Kingdom, British Sulphur Events, 26 p.
- Vautrain, 2004, Asia leads in refined-product demand growth: *Oil & Gas Journal*, no. 102.45, December 6, p. 56-62.

Internet Reference Cited

- Stell, Jeannie, 2004, 2004 worldwide refining survey, accessed February 23, 2005, via URL http://ogj.pennnet.com/Articles/Article_Display.cfm?Section=ARCHI&ARTICLE_ID=217976&VERSION_NUM=1&p=7&x=y.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Sulfur. Ch. in Mineral Commodity Summaries, annual.
Sulfur. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
Sulfur. Mineral Industry Surveys, monthly.

Other

Chemical and Engineering News, weekly.
Chemical Engineering, weekly.
Chemical Market Reporter, weekly.
Chemical Week, weekly.
European Chemical News, weekly.
Fertilizer International, monthly.
Fertilizer Week America, weekly.
Green Markets, weekly.
Industrial Minerals, monthly.
Oil & Gas Journal, weekly.
PentaSul North America Sulphur Review, monthly.
Sulfur. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
Sulphur, bimonthly.

TABLE 1
SALIENT SULFUR STATISTICS¹

(Thousand metric tons of sulfur content and thousand dollars unless otherwise specified)

	2000	2001	2002	2003	2004
United States:					
Quantity:					
Production:					
Frasch	900 ^e	--	--	--	--
Recovered ²	8,590	8,490	8,500	8,920	9,380
Other	1,030	982	772	683	739
Total ^c	10,500	9,470	9,270	9,600	10,100
Shipments:					
Frasch	W	--	--	--	--
Recovered ²	9,710 ³	8,470	8,490	8,910 ^r	9,410
Other	1,030	982	772	683	739
Total	10,700	9,450	9,260	9,600	10,100
Exports:					
Elemental ⁴	787 ^r	711 ^r	709 ^r	840 ^r	949
Sulfuric acid	62	69	48	67	67
Imports:					
Elemental	2,330	1,730	2,560	2,870 ^e	2,850 ^e
Sulfuric acid	463	462	346	297	784
Consumption, all forms ⁵	12,700	10,900	11,400	11,900 ^r	12,800
Stocks, December 31, producer, Frasch and recovered	208	232	181	206	185
Value:					
Shipments, free on board (f.o.b.) mine or plant:					
Frasch	W	--	--	--	--
Recovered ²	240,000 ³	84,700 ^e	100,000 ^e	256,000 ^e	306,000 ^e
Other	55,100	49,500	35,500	34,000	61,100
Total	295,000	134,000	136,000 ^r	290,000	367,000
Exports, elemental ⁶	57,400 ^r	52,000 ^r	43,100 ^r	54,400 ^r	63,300
Imports, elemental	39,400	22,100	26,800	70,600	76,800
Price, elemental, f.o.b. mine or plant dollars per metric ton	24.73	10.01 ^e	11.84 ^e	28.71 ^e	32.50 ^e
World, production, all forms (including pyrites)	59,300 ^r	59,500 ^r	60,600 ^r	61,900 ^r	64,100 ^e

^eEstimated. ^rRevised. W Withheld to avoid disclosing company proprietary data; included with "United States, value, recovered." -- Zero.

¹Data are rounded to no more than three significant digits except prices; may not add to totals shown.

²Includes U.S. Virgin Islands.

³Includes corresponding Frasch sulfur data.

⁴Includes exports from the U.S. Virgin Islands to foreign countries.

⁵Consumption is calculated as shipments minus exports plus imports.

⁶Includes value of exports from the U.S. Virgin Islands to foreign countries.

TABLE 2
RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE¹

(Thousand metric tons and thousand dollars)

State	2003			2004		
	Production	Shipments		Production	Shipments	
		Quantity	Value ^c		Quantity	Value ^c
Alabama	234	231	7,710	228	228	7,560
California	1,070	1,060	20,600	1,050	1,050	20,500
Illinois	466	460	11,700	528	528	10,400
Louisiana	1,210	1,210	65,400	1,280	1,280	72,600
Michigan and Minnesota	39	39	195	35	38	1,040
Mississippi	534	548	19,700	495	501	19,800
New Mexico	42	42	(2)	34	34	(2)
Ohio	104	105	4,070	122	122	3,610
Texas	2,900	2,910	81,600	3,100	3,090	110,000
Washington	122	122	(2)	113	113	(2)
Wyoming	1,360	1,360	16,900	1,540	1,540	24,200
Other ³	834	837	28,100	849	886	36,300
Total	8,920	8,910 ^r	256,000	9,380	9,410	306,000

^cEstimated. ^rRevised.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Some sulfur producers in this State incur expenses to make their products available to consumers.

³Includes Arkansas, Colorado, Delaware, Florida, Indiana, Kansas, Kentucky, Montana, New Jersey, North Dakota, Pennsylvania, Utah, Virginia, Wisconsin, and the U.S. Virgin Islands.

TABLE 3
RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES,
BY PETROLEUM ADMINISTRATION FOR DEFENSE (PAD) DISTRICT¹

(Thousand metric tons)

District and source	2003		2004	
	Production	Shipments	Production	Shipments
PAD 1:				
Petroleum and coke	229	232	236	238
Natural gas	26	26	21	21
Total	255	258 ^r	256	259
PAD 2:				
Petroleum and coke	904	896	976	978
Natural gas	44	44	43	43
Total	948	940	1,020	1,020
PAD 3: ²				
Petroleum and coke	4,430	4,470	4,780	4,810
Natural gas	617	613	512	510
Total	5,050	5,080	5,300	5,320
PAD 4 and 5:				
Petroleum and coke	1,410	1,380	1,390	1,400
Natural gas	1,260	1,260	1,410	1,420
Total	2,670	2,640	2,800	2,810
Grand total:	8,920	8,910 ^r	9,380	9,410
Of which:				
Petroleum and coke	6,970	6,970	7,390	7,420
Natural gas	1,950	1,940	1,990	1,990

^rRevised.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Includes the U.S. Virgin Islands.

TABLE 4
BYPRODUCT SULFURIC ACID PRODUCED IN THE UNITED STATES^{1, 2}

(Thousand metric tons of sulfur content and thousand dollars)

Type of plant	2003	2004
Copper ³	590	600
Zinc ⁴	51	93
Lead and molybdenum ⁴	42	45
Total:		
Quantity	683	739
Value	34,000	61,100

¹May include acid produced from imported raw materials.

²Data are rounded to no more than three significant digits, may not add to totals shown.

³Excludes acid made from pyrites concentrates.

⁴Excludes acid made from native sulfur.

TABLE 5
CONSUMPTION OF SULFUR IN THE UNITED STATES^{1, 2, 3}

(Thousand metric tons)

	2003	2004
Elemental sulfur:		
Shipments ⁴	8,910 ^r	9,410
Exports	840 ^r	949
Imports ^c	2,870	2,850
Total	10,900 ^r	11,300
Byproduct sulfuric acid:		
Shipments ⁴	683	739
Exports ⁵	67	67
Imports ⁵	297	784
Total	913	1,460
Grand total	11,900 ^r	12,800

^cEstimated. ^rRevised.

¹Crude sulfur or sulfur content.

²Data are rounded to no more than three significant digits; may not add to totals shown.

³Consumption is calculated as shipments minus exports plus imports.

⁴Includes the U.S. Virgin Islands.

⁵May include sulfuric acid other than byproduct.

TABLE 6
SULFUR AND SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE¹

(Thousand metric tons of sulfur content)

SIC ³	End use	Elemental sulfur ²		Sulfuric acid (sulfur equivalent)		Total	
		2003	2004	2003	2004	2003	2004
102	Copper ores	--	--	421	452	421	452
1094	Uranium and vanadium ores	--	--	4	2	4	2
10	Other ores	--	--	58	6	58	6
26, 261	Pulpmills and paper products	W	W	225	272	225	272
28, 285, 286, 2816	Inorganic pigments, paints, and allied products; industrial organic chemicals, other chemical products ⁴	5	W	71	154	76	154
281	Other inorganic chemicals	188	W	97	108	285	108
282, 2822	Synthetic rubber and other plastic materials and synthetics	--	--	82	70	82	70
2823	Cellulosic fibers including rayon	--	--	1	2	1	2
283	Drugs	--	--	2	1	2	1
284	Soaps and detergents	--	--	2	2	2	2
286	Industrial organic chemicals	--	--	22	25	22	25
2873	Nitrogenous fertilizers	--	--	206	209	206	209
2874	Phosphatic fertilizers	--	--	6,660	6,870	6,660	6,870
2879	Pesticides	--	--	11	16	11	16
287	Other agricultural chemicals	1,590	1,970	46	49	1,630	2,010
2892	Explosives	--	--	10	10	10	10
2899	Water-treating compounds	--	--	98	89	98	89
28	Other chemical products	--	--	45	105	45	105
29, 291	Petroleum refining and other petroleum and coal products	3,700	4,100	140	248	3,840	4,350
30	Rubber and miscellaneous plastic products	--	W	--	4	--	4
331	Steel pickling	--	--	58	9	58	9
333	Nonferrous metals	--	--	3	3	3	3
33	Other primary metals	--	--	9	6	9	6
3691	Storage batteries (acid)	--	--	13	29	13	29
	Exported sulfuric acid	--	--	1,420	26	1,420	26
	Total identified	5,480	6,070	9,700	8,770	15,200	14,800
	Unidentified	678	801	409	518	1,090	1,320
	Grand total	6,160	6,870	10,100	9,290	16,300	16,200

W Withheld to avoid disclosing company proprietary data; included with "Unidentified." -- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Does not include elemental sulfur used for production of sulfuric acid.

³Standard industrial classification.

⁴No elemental sulfur was used in inorganic pigments, paints, and allied products.

TABLE 7
U.S. EXPORTS OF ELEMENTAL SULFUR, BY COUNTRY^{1, 2}

(Thousand metric tons and thousand dollars)

Country	2003		2004	
	Quantity	Value	Quantity	Value
Argentina	(3)	25	12	604
Brazil	181 ^r	11,600 ^r	520	31,800
Canada	46 ^r	5,630 ^r	88	6,070
Chile	--	--	24	1,700
China	274 ^r	17,900 ^r	167	9,880
Colombia	4	380	19	1,380
Mexico	35 ^r	2,740 ^r	24	1,960
Morocco	236	9,230	35	1,740
Senegal	17	1,900	18	896
Switzerland	--	--	19	1,090
Other	47 ^r	4,890 ^r	23	6,170
Total	840 ^r	54,400 ^r	949	63,300

^rRevised. -- Zero.

¹Includes exports from the U.S. Virgin Islands.

²Data are rounded to no more than three significant digits; may not add to totals shown.

³Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 8
U.S. EXPORTS OF SULFURIC ACID (100% H₂SO₄), BY COUNTRY¹

Country	2003		2004	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Aruba	2,460	\$499	2,630	\$217
Canada	164,000	11,200	98,700	7,730
Chile	1	3	8,270	942
China	529	313	2,050	562
Dominican Republic	2,550	217	2,410	279
Ireland	506	795	3,490	1,530
Israel	1,120	336	236	349
Japan	135	312	67	118
Korea, Republic of	337	78	157	18
Mexico	4,030	471	44,100	2,190
Netherlands Antilles	11,200	689	10,200	484
Saudi Arabia	861	1,340	2,230	4,020
Singapore	185	56	52	55
Taiwan	547	461	595	454
Trinidad and Tobago	6,450	326	6,520	395
United Kingdom	282	231	142	24
Venezuela	2,700	211	16,800	849
Other	6,990 ^r	1,300 ^r	5,590	1,100
Total	205,000	18,900 ^r	204,000	21,300

^rRevised.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 9

U.S. IMPORTS OF ELEMENTAL SULFUR, BY COUNTRY¹

(Thousand metric tons and thousand dollars)

Country	2003		2004	
	Quantity	Value ²	Quantity	Value ²
Canada	2,080 ^e	32,000	2,010 ^e	31,300
Mexico	534	26,500	545	28,200
Other	253 ^e	12,000	295 ^e	17,300
Total	2,870 ^e	70,600	2,850 ^e	76,800

^eEstimated.¹Data are rounded to no more than three significant digits; may not add to totals shown.²Declared customs valuation.

Source: U.S. Census Bureau and PentaSul North American Sulphur Service as adjusted by the U.S. Geological Survey.

TABLE 10
U.S. IMPORTS OF SULFURIC ACID (100% H₂SO₄), BY COUNTRY¹

Country	2003		2004	
	Quantity (metric tons)	Value ² (thousands)	Quantity (metric tons)	Value ² (thousands)
Canada	386,000	\$17,800	1,920,000	\$79,400
Germany	76,800	2,570	69,300	3,750
Mexico	167,000	2,450	217,000	5,670
Spain	62,400	3,140	--	--
Sweden	57,000	3,060	95,300	4,830
Other	159,000 [†]	10,300 [†]	98,500	10,600
Total	908,000	39,200	2,400,000	104,000

[†]Revised. -- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Declared cost, insurance, and freight paid by shipper valuation.

Source: U.S. Census Bureau.

TABLE 11
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE^{1, 2}

(Thousand metric tons)

Country and source ³	2000	2001	2002	2003	2004 ^e
Australia, byproduct: ^c					
Metallurgy	654	817	899	863	865
Petroleum	30	45	60	60	60
Total	684	862	959	923	925
Canada, byproduct:					
Metallurgy	831 ^r	762 ^r	703 ^r	614 ^r	621 ⁴
Natural gas, petroleum, tar sands	8,621	8,154 ^r	7,671 ^r	7,891 ^r	8,271 ⁴
Total	9,452 ^r	8,916 ^r	8,374 ^r	8,505 ^r	8,892 ⁴
Chile, byproduct, metallurgy ^c	1,100	1,160	1,275 ⁴	1,430 ^r	1,510
China: ^c					
Elemental	290	290	290	290	300
Pyrites	3,370	3,090	3,240	3,400	3,730
Byproduct, metallurgy	1,900	2,000	2,200	2,400	2,600
Total	5,560	5,380	5,730	6,090	6,630
Finland: ^c					
Pyrites	260	270	359	341	336
Byproduct:					
Metallurgy	283	227	308	305	301
Petroleum	46	46	55	60	65
Total	589	543	722	706	702
France, byproduct: ^c					
Natural gas and petroleum	887	837	787	816	765
Unspecified	260	260 ^r	229 ^r	196 ^r	196
Total	1,150 ^r	1,100	1,020 ^r	1,010 ^r	961
Germany, byproduct:					
Pyrites	30	61	--	--	--
Byproduct:					
Metallurgy	618	684	754	701 ^r	591
Natural gas and petroleum	1,753	1,749	1,745	1,661	1,560
Total	2,401	2,494	2,499	2,362 ^r	2,150
India: ^c					
Pyrites	32	32	32	32	32
Byproduct:					
Metallurgy	359	458	458	539	539
Natural gas and petroleum	376	526	371	451	501
Total	767	1,020	861	1,020	1,070
Iran, byproduct: ^c					
Metallurgy	50	50	50	50	60
Natural gas and petroleum	963	880	1,200	1,310	1,400
Total	1,010	930	1,250	1,360	1,460
Italy, byproduct: ^c					
Metallurgy	203	203	142	127 ^r	113
Petroleum	490	540	560	565	575
Total	693 ⁴	743	702	692 ^r	688
Japan:					
Pyrites ^c	-- ^r	-- ^r	-- ^r	-- ^r	--
Byproduct:					
Metallurgy	1,384	1,319	1,326	1,281	1,263 ⁴
Petroleum	2,072	2,424	1,865	1,951 ^r	1,890
Total	3,456 ^r	3,743 ^r	3,191 ^r	3,232 ^r	3,150
Kazakhstan, byproduct: ^c					
Metallurgy	300	310	260	325	325
Natural gas and petroleum	1,200	1,400	1,600	1,600	1,650
Total	1,500	1,710	1,860	1,930	1,980

See footnotes at end of table.

TABLE 11—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE^{1,2}

(Thousand metric tons)

Country and source ³	2000	2001	2002	2003	2004 ^e
Korea, Republic of, byproduct: ^c					
Metallurgy	572	665	737 ^r	747 ^r	796
Petroleum	679 ^r	690 ^r	687 ^r	757 ^r	879
Total	1,250 ^r	1,360 ^r	1,420 ^r	1,500 ^r	1,680
Kuwait, byproduct, natural gas and petroleum ^c	512	524	634	714	682
Mexico, byproduct:					
Metallurgy ^c	474 ⁴	572	588 ^r	539 ^r	703
Natural gas and petroleum	851	878	877	1,052 ^r	1,122 ⁴
Total	1,325	1,450	1,465 ^r	1,591 ^r	1,825 ⁴
Netherlands, byproduct: ^c					
Metallurgy	123	126	124	131 ^r	137
Petroleum	428 ⁴	384	373	408	410
Total	551	510	497	539 ^r	547
Poland: ⁵					
Frasch	1,482	942	760	762 ^{r, e}	750
Byproduct:					
Metallurgy	279	277	275 ^e	275 ^e	275
Petroleum	70 ^e	133	180	175 ^{r, e}	150
Total	1,831	1,352	1,220 ^e	1,210 ^{r, e}	1,180
Russia: ^{c, 6}					
Native	50	50	50	50	50
Pyrites	400 ^r	320 ^r	350 ^r	350 ^r	300
Byproduct:					
Metallurgy	440	460	500	520	570
Natural gas	4,900	5,300	5,600 ^r	5,800 ^r	6,000
Total	5,790 ^r	6,130 ^r	6,500 ^r	6,720 ^r	6,920
Saudi Arabia, byproduct, all sources ^c	2,101 ⁴	2,350	2,360	2,180 ^r	2,230
Spain:					
Pyrites	138	71 ^e	--	-- ^e	--
Byproduct: ^c					
Coal, lignite, gasification	1	1	1	1	1
Metallurgy	454	461	544	560	488
Petroleum	115	135	140	145	145
Total	708	668	685	706	634
United Arab Emirates, byproduct, natural gas and petroleum ^c	1,120	1,490	1,900	1,900	1,930
United States:					
Frasch	900 ^e	--	--	--	-- ⁴
Byproduct:					
Metallurgy	1,030	982	772	683	739 ⁴
Natural gas	2,230	2,000	1,760	1,940	1,990 ⁴
Petroleum	6,360	6,480	6,750	6,970	7,390 ⁴
Total	10,500	9,470	9,270	9,600	10,100 ⁴
Other: ^{e, 7}					
Frasch	24	24	23	19 ^r	20
Native	422	457	449	216	161
Pyrites	284 ^r	364 ^r	372 ^r	375 ^r	367
Byproduct:					
Metallurgy	1,350 ^r	1,530 ^r	1,840 ^r	1,850 ^r	1,820
Natural gas	196	226	255 ^r	305 ^r	365
Natural gas, petroleum, tar sands, undifferentiated	1,010 ^r	1,060 ^r	1,360 ^r	1,320 ^r	1,570
Petroleum	866 ^r	785 ^r	849 ^r	810 ^r	837
Unspecified	1,080 ^r	1,120 ^r	1,090 ^r	1,140 ^r	1,150
Total	5,220 ^r	5,560 ^r	6,240 ^r	6,030 ^r	6,290

See footnotes at end of table.

TABLE 11—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE^{1,2}

(Thousand metric tons)

Country and source ³	2000	2001	2002	2003	2004 ^e
Grand total:	59,300 ^r	59,500 ^r	60,600 ^r	61,900 ^r	64,100
Of which:					
Frasch	2,410	966	783	781 ^r	770
Native ⁸	762	797	789	556	511
Pyrites	4,510 ^r	4,210 ^r	4,350 ^r	4,500 ^r	4,770
Byproduct:					
Coal, lignite, gasification ^c	1	1	1	1	1
Metallurgy	12,400 ^r	13,100 ^r	13,800 ^r	13,900 ^r	14,300
Natural gas	7,320 ^r	7,530 ^r	7,610 ^r	8,050 ^r	8,360
Natural gas, petroleum, tar sands, undifferentiated	17,300 ^r	17,500 ^r	18,100 ^r	18,700 ^r	19,500
Petroleum	11,200 ^r	11,700 ^r	11,500 ^r	11,900 ^r	12,400
Unspecified	3,440 ^r	3,730 ^r	3,680 ^r	3,510 ^r	3,580

^cEstimated. ^rRevised. -- Zero.

¹World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Table includes data available through July 15, 2005.

³The term "source" reflects the means of collecting sulfur and the type of raw material. Sources listed include the following: Frasch recovery; native comprising all production of elemental sulfur by traditional mining methods (thereby excluding Frasch); pyrites (whether or not the sulfur is recovered in the elemental form or as acid); byproduct recovery, either as elemental sulfur or as sulfur compounds from coal gasification, metallurgical operations including associated coal processing crude oil and natural gas extraction, petroleum refining, tar sand cleaning, and processing of spent oxide from stack-gas scrubbers; and recovery from processing mined gypsum. Recovery of sulfur in the form of sulfuric acid from artificial gypsum produced as a byproduct of phosphatic fertilizer production is excluded, because to include it would result in double counting. Production of Frasch sulfur, other native sulfur, pyrite-derived sulfur, mined gypsum derived sulfur, byproduct sulfur from extraction of crude oil and natural gas, and recovery from tar sands are all credited to the country of origin of the extracted raw materials. In contrast, byproduct recovery from metallurgical operations, petroleum refineries, and spent oxides are credited to the nation where the recovery takes place, which is not the original source country of the crude product from which the sulfur is extracted.

⁴Reported figure.

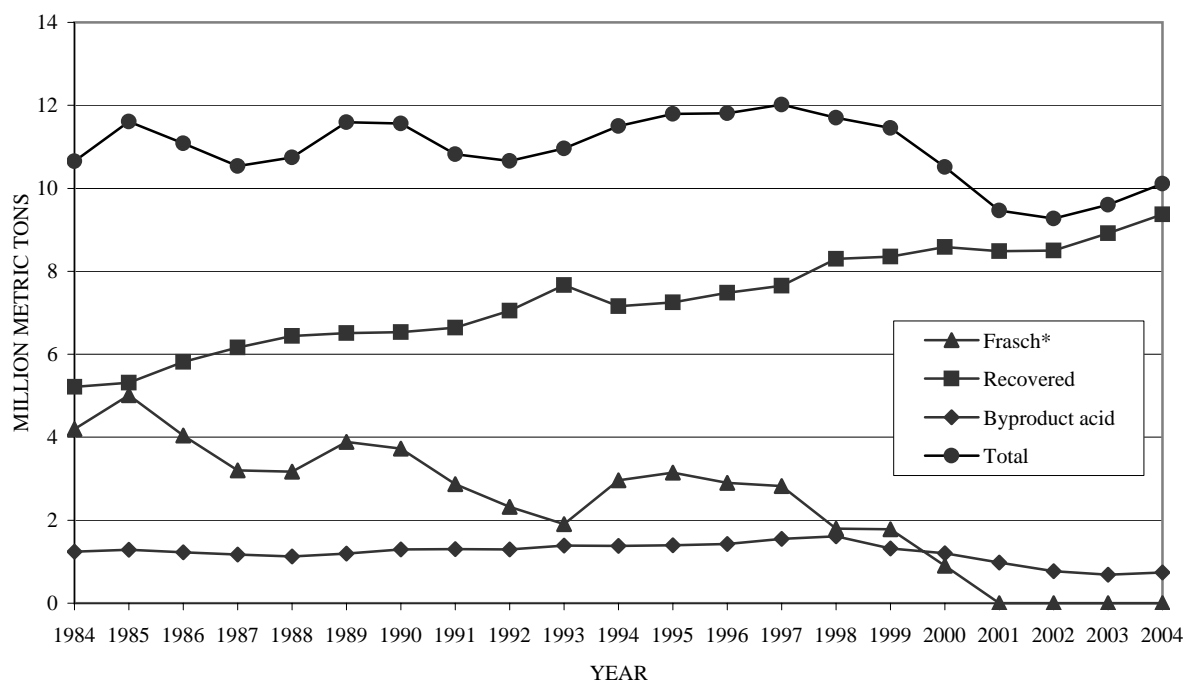
⁵Government of Poland sources report total Frasch and native mined elemental sulfur output annually, undifferentiated; this figure has been divided between Frasch and other native sulfur on the basis of information obtained from supplementary sources.

⁶Sulfur is believed to be produced from Frasch and as a petroleum byproduct; however, information is inadequate to formulate estimates.

⁷Except for the above mentioned countries, "Other" includes Albania, Algeria, Aruba, Austria, Bahrain, Belarus, Belgium, Bosnia and Herzegovina, Brazil, Bulgaria, Colombia, Croatia, Cuba, the Czech Republic, Denmark, Ecuador, Egypt, Greece, Hungary, Indonesia, Iraq, Israel, North Korea, Kuwait, Libya, Macedonia, Namibia, the Netherlands Antilles, Norway, Oman, Pakistan, Peru, the Philippines, Portugal, Qatar, Romania, Serbia and Montenegro, Singapore, Slovakia, South Africa, Sweden, Switzerland, Syria, Taiwan, Trinidad and Tobago, Turkey, Turkmenistan, Ukraine, the United Kingdom, Uruguay, Uzbekistan, Venezuela, Zambia, and Zimbabwe.

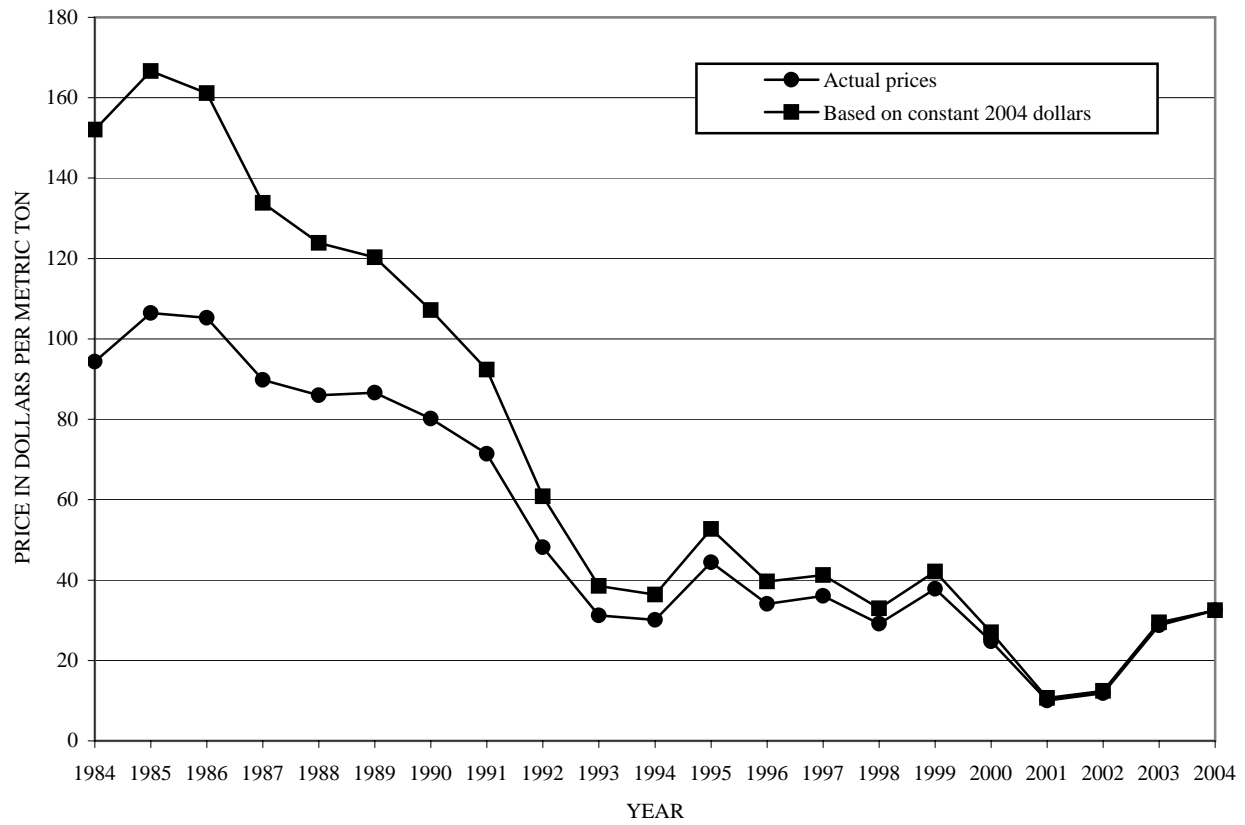
⁸Includes "China, elemental."

FIGURE 1
TRENDS IN SULFUR PRODUCTION IN THE UNITED STATES



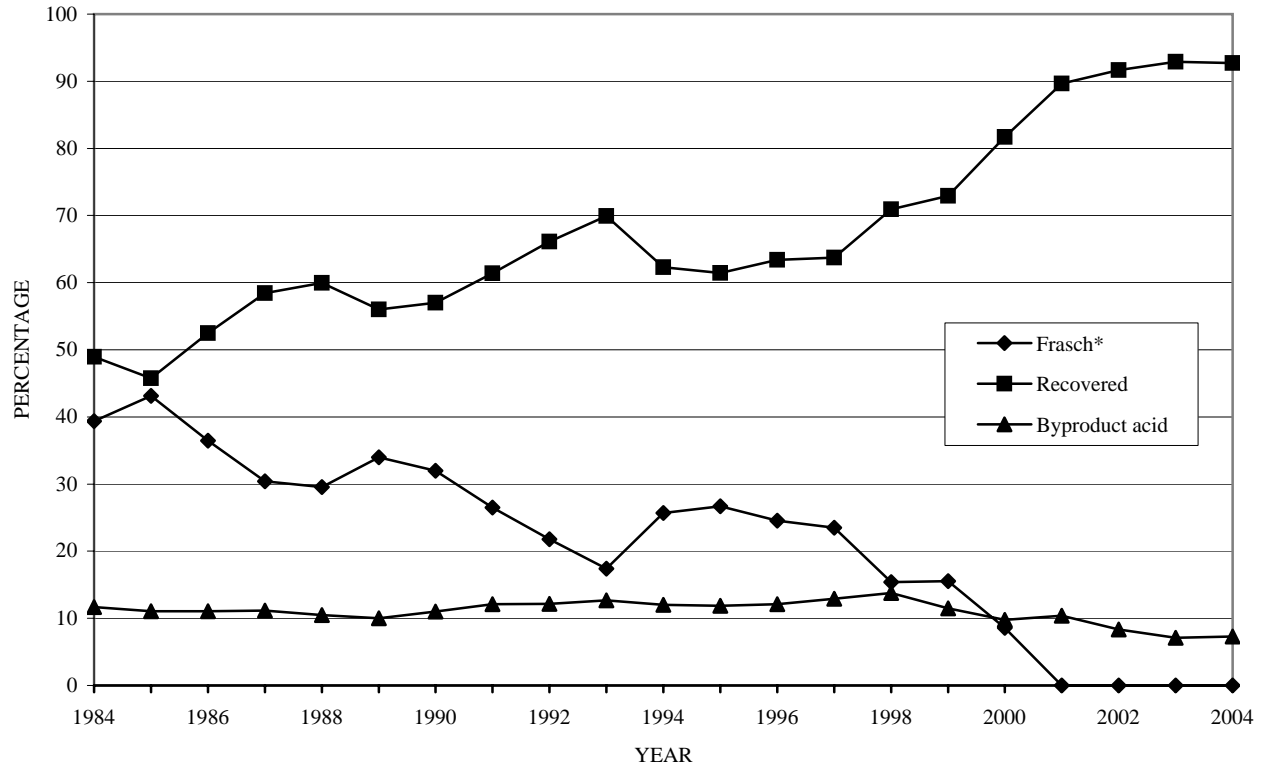
*Includes 10 months of Frasch data for 1993; the other 2 months are included with the recovered sulfur data to conform with proprietary data requirements. Data are estimates for 1994 through 2000.

FIGURE 2
ESTIMATED AVERAGE PRICE OF SULFUR IN ACTUAL AND CONSTANT DOLLARS¹



¹Based on the reported average value for elemental sulfur (Frasch and recovered), free on board mine and/or plant.

FIGURE 3
PERCENTAGE OF SULFUR PRODUCTION BY SOURCE



*Includes 10 months of Frasch data for 1993; the other 2 months are included with the recovered sulfur data to conform with proprietary data requirements. Data are estimates for 1994 through 2000.

FIGURE 4
TRENDS IN SALIENT SULFUR STATISTICS

